National Bureau of Standards

TECHNICAL NEWS BULLETIN

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The Omegatron

The omegatron is the most recent development at the National Bureau of Standards in the realm of atomic instrumentation. Basically a miniature cyclotron, the omegatron was developed by J. A. Hipple, H. Sommer, and H. A. Thomas, and has already made significant contributions in two fields: (1) It makes possible measurement of the numerical value of the faraday with exceedingly high precision. For the first time the faraday is being evaluated directly by physical methods—all previous faraday measurements have been electrochemical. (2) The value of the nuclear magneton may now be determined very precisely, so that the ratio of the mass of the electron to the mass of the proton will be known with greater precision than ever before.

Since the faraday was defined as a unit of quantity of electricity, many attempts have been made over a period of 100 years to determine its precise value, but only now with the development of the omegatron has an independent physical determination been possible. There is a discrepancy between the two best previous determinations—with the iodine voltameter and with the silver voltameter. This inconsistency has been distressing to scientists engaged in revising the tables of atomic constants, since the faraday is a key component of these tables.

In addition to absolute measurements of mass, the omegatron has many other possible uses. For example, its high resolution and extreme sensitivity make it ideal for analysis of gases and vapors, and for the measurement of nuclear packing fractions (the excess of actual mass value over mass number for any isotope), which are very important in atomic physics.

The omegatron operates on the same fundamental principle as a large cyclotron, yet the heart of the instrument is little larger than a package of cigarettes. At present the omegatron employs a rather bulky electromagnet, but a much smaller permanent magnet would serve as well and make the whole assembly desk-top size.

The functioning of the omegatron can be explained in terms of a simple physical law. If a charged particle is moving in a uniform magnetic field it will trace out a circular path. The angular velocity, ω_c, of the particle about the center of the circular path is given by the so-called cyclotron equation $\omega_c = eB/M$, where e/M is the charge-to-mass ratio of the particle, and B is the magnetic flux density. In the cyclotron this property makes it possible to accelerate charged particles to extremely high velocities. In the omegatron, however, it is used to discriminate between particles of different masses: heavier particles will have a lower angular velocity. Measurement of the angular velocity, ω_c, with the aid of accurate frequency standards and measurement of B by means of nuclear resonance methods provide an absolute determination of e/M in terms of the magnetic field strength and the cyclotron frequency alone.

In addition to a constant and uniform magnetic field, the omegatron employs a radio-frequency electric field applied at right angles to the magnetic field. If the angular frequency of the electric field is ω, then a

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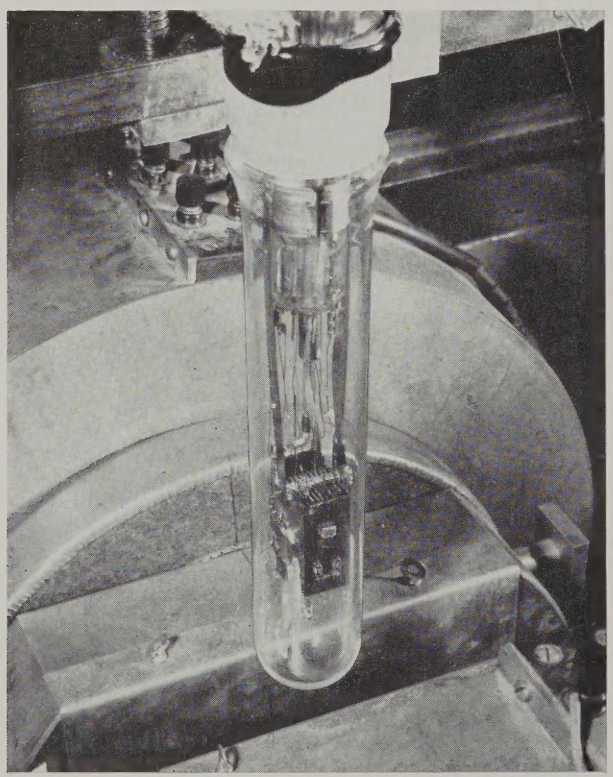
charged particle will revolve in a plane perpendicular to the magnetic field at an angular velocity of $\frac{1}{2}(\omega+\omega_c)$. The radius of the path traced out by the ion is then $R=K/\epsilon \sin (\epsilon/2)t$, where $\epsilon=(\omega-\omega_c)$, and K is a constant that depends in part on the strength of the r-f field.

If the radio frequency differs from the cyclotron frequency, the radius of the ion path will periodically increase and decrease. When the two frequencies are close together, the maximum radius of the path will be larger than when they are more widely separated, and when the frequencies are equal (in resonance) the radius of the path will increase steadily and the ion will spiral outward from the center. If a collector is placed at a fixed distance from the center of rotation of the ions, it will give maximum ion current at resonance. Resonance in the omegatron is quite sharp and can be determined very precisely.

The degree of sharpness of this resonance condition is described as the "resolution" and is defined as the width of the resonance peak at its base (expressed in cycles per second) divided by the center frequency of the peak. Resolution is proportional to the number of revolutions an ion makes before striking the collector. For greatest resolution, the ions must be held in the omegatron as long as possible. A trapping field is produced by a



Close-up view of the omegatron enclosed in an evacuated glass tube, showing the parallel-plate construction. For actual operation, the omegatron is lowered between the pole pieces of the electromagnet.

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Charles Sawyer, *Secretary*

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E. U. Condon, *Director*

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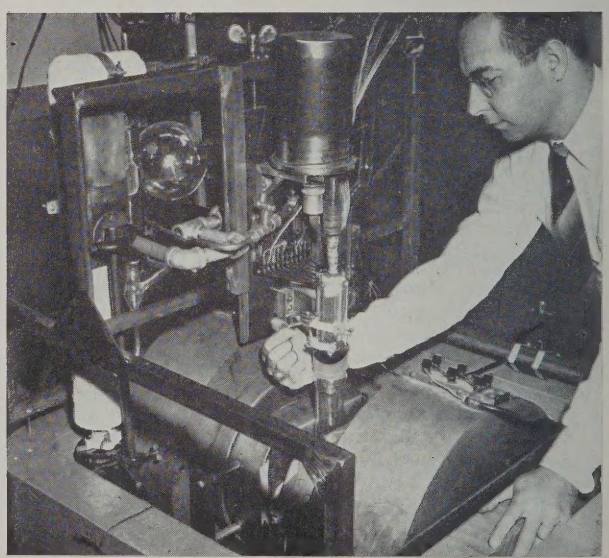


The omegatron with its associated electromagnet, vacuum system, and electrometer amplifier is shown here in use as a mass analyzer. Mr. H. Sommer is checking the position of the omegatron in the magnetic field.

positive direct-current potential applied to a set of guard rings, thus retarding axial loss of the ions. In this way, ions are held for more than a millisecond, giving them time to complete thousands of revolutions before being collected.

Resolution increases as the r-f voltage is lowered, but the accompanying decrease in ion current at the collector places a limit on the attainable resolution. The omegatron has yielded resolutions as high as 1/14,000 at unit atomic mass, with strong indications of still higher resolutions to come. The extreme sensitiveness of the omegatron permits operation with very small samples. A wide range of operating pressures is possible with the omegatron, and excellent resonance peaks have been obtained at pressures of the order of 10^{-7} millimeters of mercury.

Room-Temperature Mounting of Metallurgical Specimens

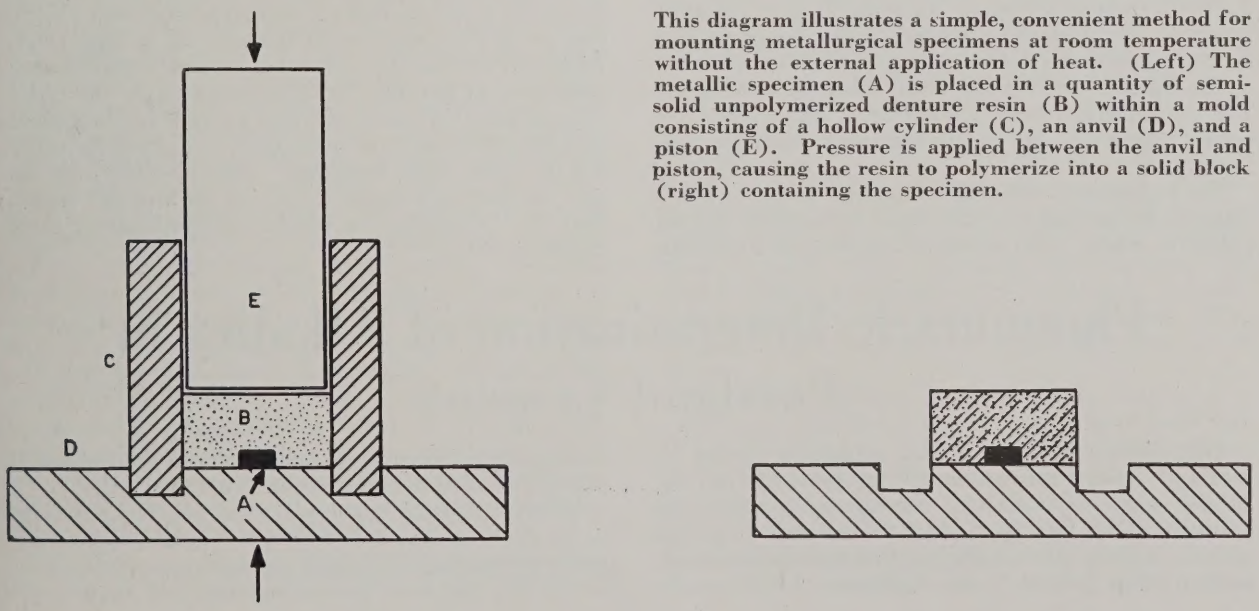
A simple, inexpensive method for mounting metallurgical specimens at temperatures only slightly above room temperature and without the external application of heat has been developed by Denton L. Smith of the Bureau's dental materials laboratory. The technique employs a denture material of modified acrylic resin as the mounting. This material consists of a polymer and a monomer, which, when mixed in the proper proportions, will polymerize or set under pressure at room temperature. As the amount of heat generated by the polymerization reaction can be controlled by varying the amount of resin present, the new procedure makes it possible to mount a wide variety of specimens for polishing and microscopic study without disturbing the crystal structure.

In studying the properties of metals, it is often necessary to embed a small metallic specimen within a larger piece of material in order that it may be conveniently held for polishing and microscopic observation. Several methods are now in use for mounting in Bakelite, lucite, or solids formed by the setting of resinous powders. However, in all these procedures the specimen is heated to a high temperature under pressure, which often causes recrystallization and change in the structure of the metal. Moreover, rather expensive equipment is usually required. The method developed at the Bureau, on the other hand, may be carried out in 15 to 30 minutes, depending on the temperature of the room, without the use of special equipment other than an inexpensive mold and a clamp or vise.

The mold used at the Bureau is of brass and consists of a hollow cylinder that fits into a depression in an anvil and contains a movable piston. The cylinder is about 1.25 in. in diameter and has 0.25-in. walls. A quantity of the unpolymerized resin containing the specimen to be mounted is placed in the cylinder, and pressure is applied between anvil and piston during polymerization by means of a bench press or vise operating in a vertical direction. A thermocouple entering the resin through the cylinder walls permits observation of the temperature rise during the reaction.

A block of resin 0.5 in. thick cured in this mold gave a temperature rise of approximately 60° C. However, when the thickness of the resin was reduced to 0.25 in., the temperature change was only about 23° C. For a block of resin 0.125 in. thick, the temperature rose approximately 10° C.

As it solidifies, the unpolymerized resin will bond



This diagram illustrates a simple, convenient method for mounting metallurgical specimens at room temperature without the external application of heat. (Left) The metallic specimen (A) is placed in a quantity of semi-solid unpolymerized denture resin (B) within a mold consisting of a hollow cylinder (C), an anvil (D), and a piston (E). Pressure is applied between the anvil and piston, causing the resin to polymerize into a solid block (right) containing the specimen.

to a piece of the solid resin placed in intimate contact with it in the mold. It is thus possible to give additional bulk to the mounting without polymerizing enough resin at one time to cause an excessive temperature rise. The specimen to be mounted is placed in a small quantity of unpolymerized resin beneath a previously cured blank in the mold. The mold is then closed, and pressure is applied. When the reaction is complete, the blank and the resin containing the embedded specimen are tightly joined together.

New Site for Radio Propagation Laboratory

Approval has been given for the development of a site at Boulder, Colorado, for additional Bureau laboratory facilities. The site, to be used initially by the Bureau's Central Radio Propagation Laboratory, consists of about 210 acres, directly south of the city and close to the campus of the University of Colorado, and is to be dedicated to the Federal Government by the Boulder Chamber of Commerce.

The National Bureau of Standards expects to erect laboratory facilities at Boulder for research in radio propagation at a cost of about $4,500,000 as authorized by Public Law 366 of the Eighty-first Congress. It is expected that actual construction work on the radio laboratory will be started at Boulder during the summer of 1951. When the laboratory is completed a research staff of about 300 people will be employed there. Most of them will be transferred from the present staff in Washington.

The radio division of the Bureau is the central Federal group for the coordination of research on the propagation of radio waves. It is also responsible for development and maintenance of the national primary standards of electric quantities at frequencies above 10 kilocycles per second. Comprehensive basic and applied research programs are administered by the radio division in radio physics and the associated geophysical phenomena of the atmosphere. Extensive laboratory investigations are being conducted on the properties of matter at radio and microwave frequencies, as well as on ways of making more precise measurements in the radio frequency region. In addition to its research function, the laboratory renders many advisory and consulting services to other agencies of the Government.

The Bureau's radio work is carried on in three units: The ionospheric research laboratory, the systems research laboratory, and the measurement standards laboratory.

The ionospheric research laboratory performs basic research on the nature of the upper atmosphere and its ability to reflect radio waves and maintains a network of 14 field stations extending over the American continents and the Pacific area.

The systems research laboratory applies radio propagation information to the practical problems of communication, and publishes a series of monthly charts predicting, three months in advance, the best frequencies for long-distance radio communication throughout the world. It also conducts research on propagation in the VHF and UHF bands, to help determine the most efficient allocation of frequencies to FM, television, and other services in these bands.

The measurement standards laboratory is largely concerned with improving the methods and standards of measurement at radio frequencies. Advances in recent years have carried this work to higher and higher frequencies and have opened up whole new fields of study. Before the war the practical use of radio waves was mostly limited to the region below 30 megacycles. Since then the whole range between 30 and 30,000 megacycles has become an object of interest for FM broadcasting, television, radio navigation, and aircraft communication.

Development of the new laboratory site at Boulder, Colorado, will make it possible for the National Bureau of Standards to carry on its work in radio propagation research on an even more comprehensive scale. Several factors entered into the selection of the site. The Bureau's technical work in radio propagation can best be carried on near a town or small city, uncongested by electrical and radio facilities. Equipment and service needs, however, make it necessary that such a location be within reasonable distance of a large city. Technical factors also call for a moderate climate and a diversity of terrain. Proximity to a major university is important, because it provides a source for competent new personnel and an opportunity for graduate training of junior staff members. The laboratory should also be close to a major center of air and rail traffic. Boulder, Colorado, was chosen on the basis of these considerations.

Photometric Determination of Alkalies in Portland Cement

The amount of sodium and potassium oxides in portland cement sets an important limitation on its use for many applications. For example, where the cement is to be combined with crushed rock or gravel to make concrete, the alkalies may sometimes react with soluble silica present in the aggregates. This causes expansion of the concrete and results in the formation of cracks and weakening of the structure.

Whereas it is highly necessary that the alkaline oxides in portland cement and cement raw materials be accurately determined, the usual gravimetric procedures for doing this are very time-consuming and require the

services of specially trained technicians. Seeking a more convenient and practicable analytical procedure, W. R. Eubank and R. H. Bogue of the Bureau's Mineral Products Division recently completed an extensive study[1] of the method of flame photometry. Their results indicate that this technique holds considerable promise for the rapid and accurate determination of alkalies in portland cement. The method has now been adopted by the Federal Specifications Board as an Alternate Standard, and by the American Society for Testing Materials as a Tentative Standard, for the determination of Na_2O and K_2O in portland cement.

In the method of flame photometry, the solution to be analysed is atomized into a flame. Light characteristic of each element to be determined is then isolated, and its intensity is measured. In this way the principles of analytical spectroscopy are applied under conditions that allow rapid determinations to be made with relatively simple apparatus by personnel having only moderate training.

In the Bureau's investigation, a group of five cements was subjected to repeated analysis for Na_2O and K_2O by means of the flame photometer over a period of several weeks. The results, expressed as percentages of Na_2O and K_2O, were highly consistent. The standard deviation varied from 0.005 to 0.017 for Na_2O and from 0.000 to 0.023 for K_2O. The maximum spread for any cement was 0.05 percent for Na_2O and 0.06 percent for K_2O.

To evaluate the personal factor in these determinations, the flame-photometric results obtained on a series of cements by three operators using two different units of the instrument were compared. The average maximum variation from operator to operator was only 0.03 percent for Na_2O and 0.04 percent for K_2O, indicating that the personal factor in operating the flame photometer is small and that a highly trained operator is not necessary.

Use of the flame photometer in this work requires standard solutions of known alkali concentration that provide the basis of reference in each determination. These solutions must be so constituted that the excitation conditions they produce in the flame are similar to those produced by the solutions to be analyzed. The ideal standard solution would thus be composed of the same elements in about the same concentrations as the cement solutions to be analyzed. Such standard solutions could be approximated by the addition of definite amounts of sodium and potassium chlorides to a cement solution of known but low alkali content. However, there are serious objections to the use of a cement for making up the standard solutions. In the first place, cements containing less than 0.1 percent of both Na_2O and K_2O are not commonly available. Furthermore, any error in the content of those oxides as determined gravimetrically would be reflected in all subsequent photometric determinations. Also, if lithium oxide is present, it will introduce an error in the gravimetric value for Na_2O, which, as commonly determined, includes any Li_2O that is present.

[1] For further technical details, see Studies on the flame photometer for the determination of Na_2O and K_2O in portland cement, William R. Eubank and Robert H. Bogue, J. Research NBS **43**, 173 (1949) RP2019.

The flame photometer is used to make rapid, accurate determination of sodium and potassium oxides in portland cement. The solution to be analyzed is poured in through the funnel. It is then atomized into a flame. Light characteristic of each element to be determined is isolated, and its intensity is indicated on the scale beside the funnel. Propane gas is used to produce the flame.

A series of standard solutions was therefore prepared containing calcium ion and hydrochloric acid in approximately the same concentration as would occur in the solutions of portland cement to be analyzed. When these standard solutions were used, the values for Na_2O and K_2O obtained with the flame photometer were in excellent agreement with those obtained by gravimetric analysis. The Bureau is therefore recommending the CaO–HCl solutions as standards in the flame photometric determination of alkalies in portland cement.

An important consideration in using the flame photometer is the gas employed for producing the flame. This gas must be of constant composition and pressure and free of materials that may interfere with the spectral emission. For alkali determination, it should also provide a flame temperature that will readily excite the alkali elements without affecting other elements that require higher temperatures for excitation. Propane was found to be nearly ideal for exciting the alkali elements with a minimum of interference from other causes.

The internal-standard procedure, often employed in spectrographic determinations, is sometimes used with the flame photometer. In this method, which employs a dual optical system, the emitted light-intensity ratios of the element sought and of another element introduced in known concentration are measured, rather than the absolute light intensities of the element sought, as in the direct-intensity method. The disturbing effects caused

by gas and air-pressure fluctuations, the presence of foreign ions and molecules, and viscosity differences are thus minimized. The Bureau therefore made a comparative study of the relative advantages of the two procedures for determination of the alkali elements in portland cement and cement materials.

In either case the flame-photometric results compared favorably with the values obtained by gravimetric analysis. However, the Bureau does not recommend the internal standard method for determination of the alkali oxides in portland cement. The weakness of the method lies in the introduction of a fixed amount of lithium to both the standard and unknown solutions in order to obtain intensity ratios of the alkali elements to the standard. As lithium is unfortunately present in some raw materials that may be used in cement manufacture, the reliability of the internal-standard method is thus open to question.

Creep of Ingot Iron

It is well known that if the temperature is sufficiently high, any metal will deform continuously under a constant stress, i. e., will "creep". In a previous investigation at this Bureau involving the influence of strain rate and temperature on the mechanical properties of Monel metal and copper during creep, it became evident that the ductility of both metals increased with increase in strain rate and with decrease in temperature.[2] It was further observed that the third stage of creep [3] was sometimes initiated by the formation of microscopic cracks. With sufficiently slow strain rates at elevated temperature, specimens of Monel and copper failed without local contraction (necking). Because both metals are face-centered cubic metals, the creep-testing program was extended to include a study of effect of strain rate and temperature on the behavior of cold-drawn ingot iron, a body-centered cubic metal.[4]

For this investigation, creep tests were made at different strain rates and temperatures on ingot iron initially cold-drawn to approximately 13-percent reduction in area. Some tests were discontinued after the beginning of the third stage of creep; these specimens were subsequently tested in tension to fracture at room temperature. Other specimens were tested in creep at 500°, 600°, 700°, and 800° F to complete fracture. In carrying these specimens to fracture, the rate during the third stage was maintained approximately constant and equal to that in the second stage by adjusting the load. This procedure of maintaining a constant rate beyond the beginning of the third stage was essential in determining the effect of strain rate on ductility at fracture. (Previous work (see footnote 2) has shown that when a creep test is made under constant load the increased rate in the third stage tends to cause an increase in the extension at fracture.) Each specimen tested in creep was heated in air to the desired temperature and held for 48 hours before loading. The load was applied in selected increments in order to produce a nearly constant rate of extension of 30 to 50 percent in 1,000 hours until the desired ultimate load for testing was attained. Thereafter the load was not changed in any specimen until the test was completed or the third stage was reached.

Time-extension curves for specimens tested to the third stage of creep revealed that the change in extension with time during the second stage frequently does not occur uniformly but varies in a cyclic manner. During a cycle, the change in extension often ranges from relatively high to low or negative values. The frequency and amplitude of these cycles apparently depends upon the temperature, strain rate, and elapsed time in the second stage of creep. The trends were (1) a decrease in the amplitude and frequency of the cycles with an increase in either temperature or strain rate and (2) a decrease as the deformation or time approaches the beginning of the third stage. At sufficiently high strain rates and temperatures, strain aging is not manifested in the shape of the extension-time curve, and the rate is nearly constant in the second stage. These cycles, it is believed, result from a combination of strain hardening, strain aging, and recovery (or annealing) of the iron.

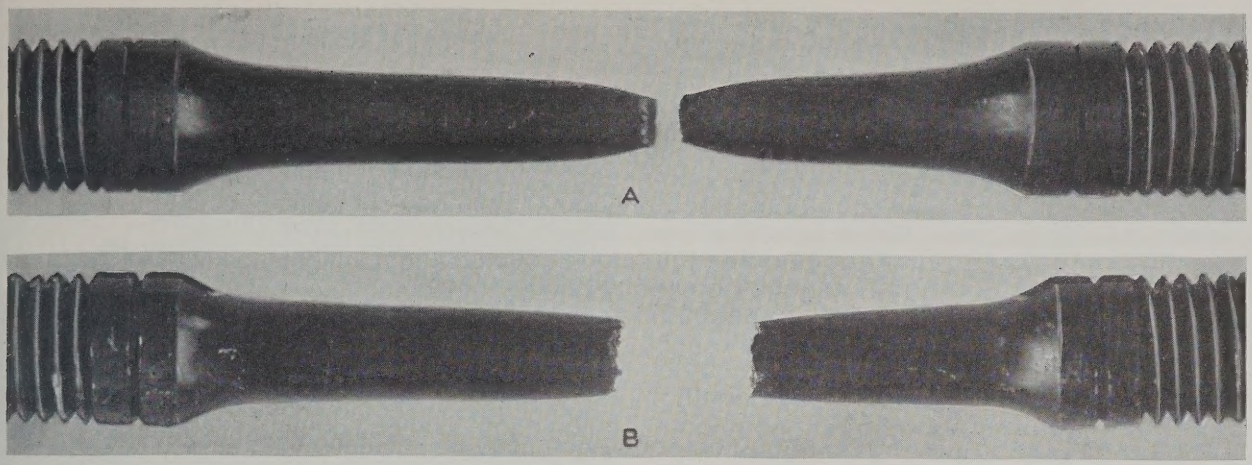
The relation between true stress and creep rate in the second stage was shown in experiments at different temperatures. With the selected rate of loading (30 to 50 percent extension in 1,000 hours), the experimental values obtained at test temperatures of 600°, 700° and 800° F did not fall on a straight line when plotted on logarithmic coordinates. Instead, the curves drawn through the experimental values deviated from linearity by bending downward with the lower and upward with the higher ranges in strain rate used at each temperature. The tests at 800° F were not extended for relatively slow rates, but it would be expected that the results of such tests would also follow the downward path. Although these stress-strain rate curves follow the same general pattern, the curves are not parallel, and the relative positions where the bends occurred were influenced by the temperature of testing. The pronounced downward curvature was shifted to a lower creep rate as the temperature was changed from 600° to 700° F and the upward curvature to higher rates as the temperature was decreased. Similar trends were shown in the curves when the experimental values for true stress were plotted against the logarithm of the strain rate.

For the initially cold-worked ingot iron, the use of a linear relationship in either a log-log or semi-log plot of true-stress versus strain-rate is not justified for extrapolating to slow strain rates (long service life) at 600° or 700° F. In general, resistance of the metal

[2] For further technical details, see Influence of strain rate and temperature on the mechanical properties of Monel metal and copper, D. J. McAdam, Jr., G. W. Geil, and D. H. Woodard, Proc. Am. Soc. Test. Mat. 46, 902 (1946).

[3] The three consecutive stages of creep are (1) creep at a decelerating rate following initial loading, (2) creep at an approximately constant rate, and (3) creep at an accelerating rate leading to fracture.

[4] For further technical details, see Influence of strain rate and temperature on the creep of cold-drawn ingot iron by William D. Jenkins and Thomas G. Digges, J. Research NBS 43, 117 (1949) RP2013.



Photographs of specimens after fracturing in creep. Specimen A was tested at 600° F with a strain rate of 380 percent per 1,000 hours. Necking extended over a considerable portion of the gage length. Specimen B was tested at 700° F with a strain rate of 46 percent per 1,000 hours. Necking was confined principally to the region near the fracture.

to both creep and fracture increases with an increase in the strain rate.

The effect of temperature on the resistance to creep of ingot iron was revealed by a comparison of several stress-strain rate curves. From these it was obvious that the resistance to creep increased as the test temperature decreased. The resistance to creep at 700° F was materially increased by decreasing the rate of extension in the first stage during loading from about 40 percent in 1,000 hours to 3 percent in 1,000 hours; the plastic extension at fracture was also affected by this change in rate of loading. In previous investigations, little attention was given to controlling the rate of extension during the first stage. The rate of loading is a factor that merits further study.

Although the strain rate was controlled and maintained nearly constant in the third stage of creep, considerable "necking" occurred in each specimen tested to fracture. In some cases, the necking was confined principally to a relatively narrow region in the vicinity of the fracture, whereas in other specimens there was a more gradual necking over a considerable portion of the gage length. Both the extension and reduction of area at fracture were affected by the manner in which the specimen necked but not necessarily to the same degree.

The specimens tested into the third stage of creep (not fractured) were unloaded and then cooled in the furnace to room temperature. A summary of the results of measurements made at room temperature for change in diameter over the entire gage length and the determination of extension during creep showed no evidence of local contraction or visible surface cracks in any of these specimens except one, which revealed only a slight indication of necking. Furthermore, in another specimen tested (at 500° F) to nearly the end of the third stage, no evidence of cracking was observed in a metallographic examination at 500 and 1,000 diameters of the necked section extending from the axis to the surface. Thus, the third stage of creep began without necking or without the presence of cracks of microscopic dimensions. However, regardless of the rate of extension, some necking occurred in the third stage of creep in each specimen tested to complete fracture.

Some of the structural features of the ingot iron before and after testing in creep were revealed by photomicrographs. The average size of the ferrite grains in the initially cold-drawn bar corresponded to the lower range of American Society for Testing Materials grain number 5. These grains were elongated only slightly in the direction of cold-working, and the inclusions were frequently alined in streaks parallel to the direction of hot- and cold-working. Some of these inclusions were fractured during hot- and cold-working, but apparently no further change occurred in either their form or distribution during creep. Although the ingot iron contained the usual numerous oxides, these inclusions had no appreciable effect on the type of fracture produced in creep.

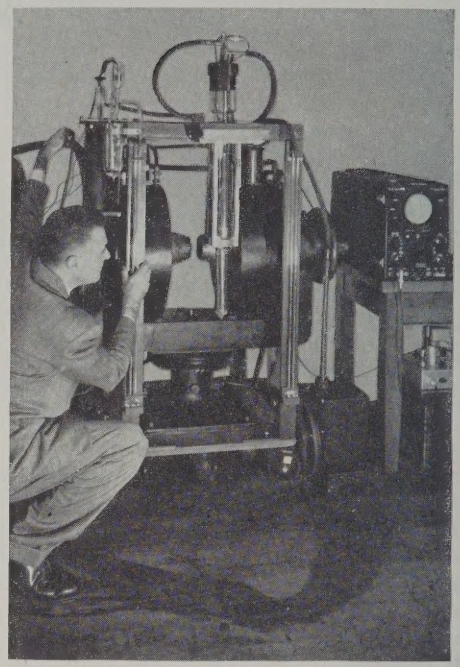
The fractures of the specimens tested at 600° F with strain rates of 1.6, 380, and 1340 percent in 1,000 hours were essentially transcrystalline, whereas the fractures of all specimens at 700° and 800° F were predominantly intercrystalline. The maximum distortion of the grains during creep was obtained in a specimen tested at 600° F with a relatively high strain rate. Cracking in this specimen, which had a pronounced neck and relatively high ductility, was observed only in the regions of complete separation. Appreciable elongation of the grains also occurred in another specimen tested at 600° F with a creep rate of 1.6 percent in 1,000 hours, but there was some separation of the grains in regions away from the position of complete fracture. The general trend was for the flow to increase with a decrease in test temperature and to increase with an increase in strain rate. The tendency for the ferrite grains to separate in the regions away from the portion of complete fracture was promoted by decreasing the strain rate and by increasing the temperature.

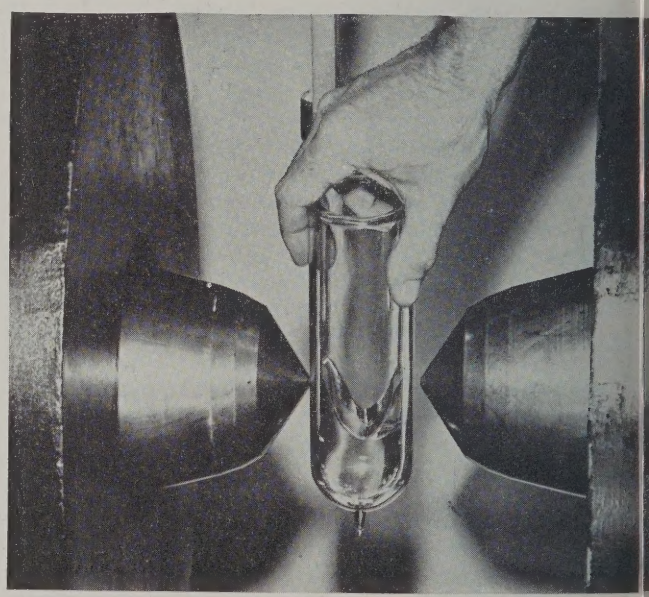
Velocity of Second S

In recent low-temperature experiments,[5] J. R. Pellam and R. B. Scott of the Bureau's cryogenics laboratory have for the first time succeeded in measuring the velocity of second sound at temperatures well within one degree of absolute zero. Study of second sound, the unique wavelike process of heat transfer occurring only in helium II, offers a most sensitive means for investigating the unusual properties of this substance at very low temperatures—properties that in many ways seem to constitute a fourth state of matter. Thus the results obtained at the Bureau, in addition to settling a point of long-standing disagreement among low-temperature physicists, provide a useful orientation for mapping future research efforts in this field and should eventually lead to a better understanding of the nature of matter.

When cooled to 2.19° K (the λ-point), ordinary liquid helium (HeI) undergoes a transition to HeII with a radical alteration of many of its properties. Although in appearance a liquid, HeII exhibits characteristics of each of the three states of matter. In some ways it acts as though it has no viscosity, flowing, apparently without friction, through virtually vacuum-tight openings and up the side of a containing vessel at remarkable speed in seeming defiance of gravity. Its direction of flow through narrow orifices may be controlled entirely by the introduction of temperature differences. At the λ-point, the thermal conductivity of HeI increases very abruptly by a factor of three million, giving an apparent value for HeII much greater than that of any other substance. This is because heat is propagated in HeII as waves of second sound, whereas in other materials heat flow is purely a diffusion phenomenon. All of these effects may be explained by the presence in HeII of a superfluid. The atoms of the superfluid have had their energies reduced by cooling to the point where thermal motion has ceased, yet the intermolecular forces are not great enough to produce a rigid solid. As a result, viscosity practically disappears, and other remarkable properties are observed.

The existence of thermal waves in HeII was predicted first by Tisza [6] and later independently by Landau [7] in their efforts to explain the unusual physical properties of the substance. Each of these theorists regards HeII as a mixture of a normal fluid, containing most of the thermal energy of the liquid, and a superfluid, but they differ in the quantity of energy attributed to the atoms of the superfluid. Landau considers the superfluid as possessing no thermal energy at all, whereas Tisza would assign to these atoms a small amount of heat energy. According to both theorists, the application of heat to some part of a quantity of HeII upsets the equilibrium between the two fluids, resulting in a migration of the two types of atoms in opposite directions. As the superfluid is assumed to have virtually





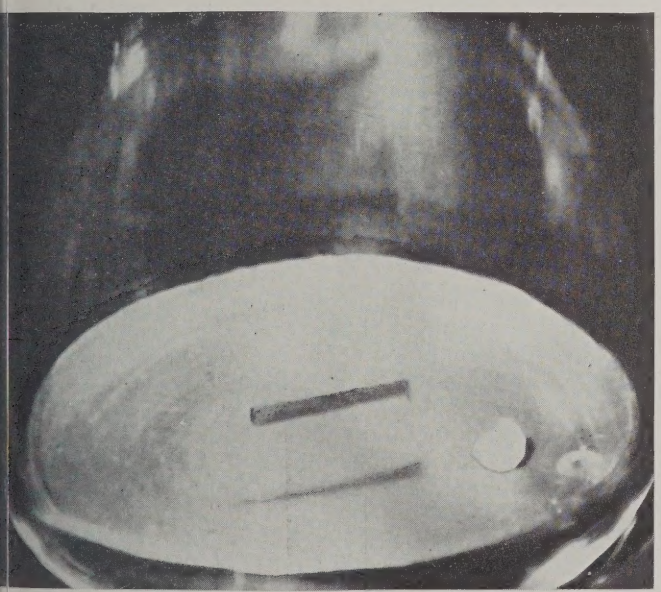
Measurement of second sound velocity takes place within th powerful electromagnet. (A) Gaseous helium is admitted the intermediate dewar and its temperature further reduced second sound transmitter-receiver in liquid helium. Cooli technique (B). A paramagnetic salt, supported between th causes a sharp temperature drop. (C) The fountain effec Helium spurts through the emery powder and out the top o of liquid oxygen are strikingly demonstrated in the field of temperature near absolute zero, it produces an electric cur up a magnetic field that repels the magnet and supports it

[5] For further technical details, see Second sound velocity in paramagnetically cooled liquid helium II, by J. R. Pellam and R. B. Scott, Phys. Rev. **76**, 869 (1949).

[6] L. Tisza, J. de Phys. et Rad. **1**, 165, 350 (1940); Phys. Rev. **72**, 838 (1947); also **75**, 885 (1949).

[7] L. Landau, J. Phys. USSR **5**, 71 (1941); also **8**, 1 (1944); also Phys Rev. **75**, 884 (1949).

l Near Absolute Zero



three coaxial dewar flasks supported between the poles of a ermost dewar. After liquid helium has been transferred to ing, the gas in the inner chamber condenses, immersing the l° K is then obtained by the "adiabatic demagnetization" ces is magnetized. Subsequent demagnetization of the salt l HeII occurs when the lower part of the tube is warmed. e in a spectacular fountain. (D) The magnetic properties magnet. (E) When a magnet approaches a tin plate at a plate that continues to flow indefinitely. This current sets

zero viscosity, no resistance to this internal convection is presented by the body of the liquid. A sustained internal vibration between the fluid components is thus possible, and this internal convection type of wave propagation constitutes second sound. Since second sound is basically a "concentration wave", consisting of a progressive change in the relative proportions of normal fluid and superfluid at any point in the liquid, it can be detected only by a temperature-sensitive device, such as a bolometer, rather than by a microphone.

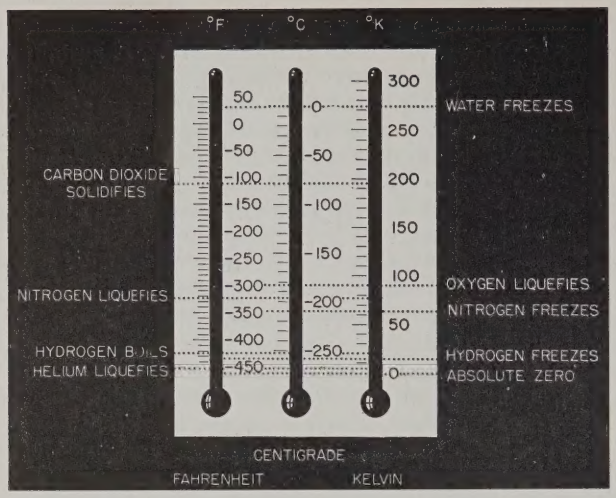
Starting with the two-fluid hypothesis, both Tisza and Landau derived thermodynamic relationships that led to equivalent expressions for the velocity of second sound. Their equations express velocity as a function of temperature, entropy, and the ratio of the concentration of superfluid to that of normal fluid (both functions of temperature). This relationship accounts adequately for observed values of second sound velocity between about 1.3° K and the λ-point (2.19° K). However, to apply the theory at temperatures below 1° K, it is necessary to make some kind of an assumption as to how thermal energy is shared between the normal fluid and the superfluid components. Landau's more drastic partition of energy between the two fluids leads to the prediction of a sudden rise in the velocity of second sound below 1° K, whereas Tisza's postulate results in decreasing velocity below this temperature. Since the energy associated with the superfluid becomes important only at the lowest temperatures, the decision as to the validity of the two hypotheses had to await measurements of second sound velocity below 1° K.

Various aspects of second-sound propagation in HeII are now under study at this Bureau as part of a broad program of basic research on the properties of matter at extremely low temperatures. Experimental investigations in this field, together with theoretical research, are expected to aid in forming a clearer picture of the liquid and solid states. In order to carry forward the present theory of the nature of HeII near absolute zero, it was necessary to make a choice between the assumptions of Landau and those of Tisza. The Bureau therefore undertook a laboratory study of the velocity of second sound below 1° K. The resulting data provide a clear-cut decision in favor of Landau's hypothesis of energy partition.

The Bureau's investigation of second-sound velocity employs a recently developed pulse method [8] so that signals that would otherwise be quite difficult to detect are presented on an oscilloscope screen for visual observation. Pulses or bursts of heat generated electrically within liquid HeII travel through the helium and are detected upon arrival at a temperature-sensitive element; meanwhile, their transit time is measured accurately by electronic timing circuits.

Cooling below 1° K is achieved by the method of adiabatic demagnetization, in which crystals of a paramagnetic salt immersed in a part of the HeII are carried through a special magnetizing and demagnetizing cycle. Alinement of the ionic dipoles during magnetization

[8] J. R. Pellam, Phys. Rev. **73**, 608 (1948); **75**, 1183 (1949).



Fahrenheit, Centigrade, and Absolute (Kelvin) thermometer scales showing significant temperatures in low-temperature physics between absolute zero and the melting point of ice.

produces a temporary heating which is soon (within perhaps 3 minutes) offset by concurrent helium evaporation. Subsequent demagnetization releases the dipole alinement, and a sharp temperature drop occurs within the crystals. Because of the remarkable speed with which heat is transferred in HeII, this cooling is rapidly transmitted to the adjacent liquid helium and in turn to the portion of the HeII that surrounds the equipment for measurement of second-sound velocity.

To reduce heat exchange with the surroundings, the paramagnetic salt (iron ammonium alum) and the apparatus for transmitting and receiving second sound are mounted within the innermost of three concentric dewar flasks. The outermost dewar contains liquid air, whereas the intermediate and innermost vessels contain liquid HeII. The innermost chamber is suspended in a vacuum by a narrow glass capillary, which provides the only heat path from the outside. This dewar system is mounted on a movable carriage so that the salt crystals can be centered between the poles of a powerful water-cooled electromagnet; at other times the dewars can be slid to an outer position for receiving liquid helium from a portable liquefier.

By pumping off helium vapor through a vacuum connection, the temperature of the intermediate dewar is lowered to about 1.4° K. The temperature of the liquid HeII in the innermost dewar may then be brought down to about 1.1° K by pumping through the capillary suspension. At this point a magnetic field of about 12,000 oersteds is produced across the poles of the electromagnet, magnetizing and heating the paramagnetic salt. However, the heat thus produced is almost immediately lost from the inner chamber by evaporation of liquid helium and removal of the helium vapor through the vacuum connection. The magnetic field is then removed, and the resulting demagnetization of the salt causes the temperature of the crystals to fall rapidly.

Use of the pulse method to measure second-sound velocity provides an instantaneously indicating, direct-reading technique that avoids the difficulties inherent in the relatively slow and heat-producing standing-wave method used by Peshkov [9] in his original observation of second sound. Disk-shaped heat pulses of about 100 microseconds' duration are generated electrically at the second-sound transmitter, which consists essentially of a disk-shaped electrical resistor a few inches below the paramagnetic crystals. These pulses travel upward through the HeII at their characteristic wave velocities to register on the receiving element about 2 inches above. The receiver is a temperature-sensitive resistor made of a thin, disk-shaped carbon layer and carrying a small, steady current. Upon arrival at the receiver, each pulse of second sound produces a small voltage pulse that is amplified and presented on vertical plates of an oscilloscope. As the horizontal time sweep of the oscilloscope is triggered at the start of the initial transmitter pulse, the horizontal position of the signal is a direct indication of wave velocity.

Previous measurements by other investigators had shown that as temperature is decreased from the λ-point (2.19° K) the velocity of second sound rises steadily from an apparently zero value (at the λ-point) to a maximum of just over 20 meters per second at 1.65° K. Although a definite maximum was observed at this temperature, the value fell only slightly with further cooling, indicating a gradual leveling-off in the temperature range just above 1° K. Peshkov had in fact noted an apparent minimum of 18.4 meters per second at 1.1° K, after which the velocity evidently increased slightly at 1.05° K. More recently, Mauer and Herlin, using a modification of Pellam's original apparatus, verified this minimum in observations from 0.89° to 1.1° K. However, observation of velocities over a larger temperature range was necessary to settle unambiguously the question of whether the velocity rose or fell below 1° K and thus afford a choice between the microscopic phases of the theories of Tisza and Landau.

In the demagnetization experiment performed at this Bureau, not only was an unmistakable increase in velocity observed below 1° K, but the value nearly doubled, rising smoothly from the minimum of 18.4 meters per second at 1.1° K to 33.9 meters per second at a temperature estimated to lie somewhere between 0.5° and 0.7° K. By reducing heat leaks and introducing other refinements, extension of the observations down to 0.1° K appears feasible.

It may be surmised that Landau's more precise division of energy between the two fluids leads to a greater "internal stiffness" or "thermomechanical rigidity" for HeII, particularly at the lowest temperatures. Inasmuch as the wave motion of second sound is a progressive variation in the relative concentration of the two fluid components, this condition should involve greater "restoring force" toward the equilibrium concentration (and the ambient temperature). As in classical me-

[9] V. Peshkov, J. Phys. **10**, 389 (1946); also **8**, 381 (1944); also J. Exper. Theor. Phys. USSR **18**, 951 (1948).

chanical waves, the greater stiffness may be associated with greater wave velocity. If, on the other hand, some of the thermal energy were shared by the fluid components, internal stiffness would be lessened, especially at very low temperatures, resulting in a decrease in velocity below 1° K.

The Bureau's verification of Landau's theory should renew interest in the possibilities of new methods for producing extremely low temperatures. When liquid HeII passes through a small opening, 3 microns or less in diameter, atoms of the normal fluid are left behind. Since the superfluid atoms passing through the orifice do not take any thermal energy with them, the temperature on one side of the opening is considerably reduced. It should thus be possible to obtain a substantial reduction in temperature by repeatedly passing HeII through small openings, as was once suggested by Kapitza.

Statistical Engineering

Statistical engineering is the name given to that phase of scientific research in which statisticians advise, guide, and assist other scientists in the conduct of experiments and tests. In particular, it is concerned with the statistical aspects of the collection, reduction, analysis, and interpretation of data. At the National Bureau of Standards this is carried out by the staff of the Statistical Engineering Laboratory as a service to the Bureau, to other Government agencies, and to the public at large.

In any scientific investigation the object of the investigation determines what data are to be collected; how the data are collected determines the inferences, predictions, and decisions that can be made; and the quantity of data collected determines the precision of the results. Very often these factors should be considered from the point of view of statistical engineering. "In these days when so much emphasis is properly being placed on economy in Government research operations, it is important to take advantage of the substantial savings that can be effected by substituting sound mathematical analysis for costly experimentation. In science as well as in business, it pays to stop and figure things out in advance." [10]

The statistical consultants on the staff of the laboratory are experts in planning the collection of data to obtain the greatest amount of desired information under given limitations of personnel, equipment, and materials. When an experiment or test is preceded by careful statistical planning, the experimental data that are gathered will be subject to simple and unambiguous interpretation. A change in the role of the statistician from that of a mere analyzer and interpreter of data to that of coplanner in scientific investigations was begun by the British biologist-statistician R. A. Fisher, founder of the science of the statistical design of experiments. The effect of this change is only now being felt widely in engineering and the physical sciences.

Two antithetical risks are involved in any scientific investigation: First, there is the risk something may be "discovered" that isn't so; second, that something that is so may not be discovered. It is more important from the over-all viewpoint of science to avoid errors of the second kind. If a scientist should announce a discovery that is false, he will be found out in due course by those who attempt to confirm it; but if he fails to make the discovery and, especially, if he makes a negative proclamation, others may discontinue their search in that direction and the truth may go long undiscovered. This situation is aggravated by a lack of space in scientific and technical journals, preventing publication of the full data for most studies. In the absence of full data, two or more "negative" results will often be interpreted as an "emphatic negative," although a careful independent analysis of all of the data might reveal a positive conclusion. There are cases where this has happened. Every scientist is thus under an obligation to minimize his risks of committing errors of either kind, particularly the second.

Each investigator should see to it that his data are obtained through a statistically sound procedure. There should be a built-in randomness in an experiment so that the effects of uncontrolled factors will tend to balance out, and so that valid adjustments can be made for likely sources of bias. If it is not possible to publish the data in full, a summary should be made that preserves all of the relevant evidence carried by the original data. It should be possible to estimate the reliability of the results from an examination of the data alone.

An important concern in the proper planning of experiments is to obtain a random sample of the population under study. It is often troublesome and costly to do this, but at the very least an experiment or test should take into account variations in equipment and materials. The scope of the experiment must bracket the circumstances under which the results are likely to be applied.

Statistical Services

The Statistical Engineering Laboratory, as well as the other units of the National Applied Mathematics Laboratories of the National Bureau of Standards, cooperates on the statistical phases of scientific experiments and engineering tests whenever it can. The work of the laboratory has already shown that statistical principles and techniques are even more useful in physical-science and engineering measurement than they are in agricultural and industrial work, where many of them were first developed. In the physical sciences, statistics is especially helpful in the evaluation of errors in measurement and often indicates ways of reducing the errors themselves or their effect on the final results. On the other hand, new problems in the physical sci-

[10] Dr. E. U. Condon, Director of the Bureau, in the Foreword to the Prospectus for the National Applied Mathematics Laboratories, 1947.

ences are revealing needs for further development in statistical theory and methodology.

In addition to its consulting services, the Statistical Engineering Laboratory carries on several other activities that contribute to this development. Manuals on selected phases of statistical methodology, glossaries of statistical engineering terms, and guides to statistical literature are in preparation by the staff. Special tables of statistical functions, as well as other aids to the application of modern statistical methods, are organized and published as the need arises. The staff offers courses in the NBS Graduate School on the principles and techniques of statistical inference as applied to the planning and interpretation of scientific experiments and engineering tests. The laboratory also conducts basic research on appropriate topics in the mathematical theory of probability and mathematical statistics.

Statistical Methodology

Logic, mathematics, and statistics are basic disciplines that provide the principles and tools for describing and analyzing phenomena in science and everyday affairs. They provide a solid methodological support for inferences and prediction and mediate between research and its applications. In spite of the connectedness of these three subjects, many physicists, chemists, and engineers, although they use classical applied mathematics daily in their work, have been slow to adopt statistical methods in their respective fields.

The foundations of statistical method were laid in large part in the writings of Gauss early in the nineteenth century. Adopting some of the ideas of Laplace, he set forth the basic principles and techniques of the theory of errors and, virtually single-handed, developed the method of least squares essentially as it is used today to obtain the "best" estimate of a measured physical quantity. Least squares gives the researcher two things: a convenient rule for achieving objectivity in an investigation and a powerful method of reducing observational data to a form that can be easily interpreted. The theory of errors is then valuable in determining the reliability of the experimental results. But these uses are only in connection with the analysis of data already in hand. For nineteenth century physical science, the classical theory of errors and the method of least squares were adequate. But statistical theories and methods of greater effectiveness are needed if they are to help today, from the beginning to the end of experiments, in planning experiments as well as in analyzing the results.

In addition to the classical theory of errors and method of least squares, physical scientists and engineers have at their disposal the statistical principles and techniques of (1) lot-by-lot *acceptance inspection*, developed by H. F. Dodge, H. G. Romig, and others, as a guide in the procurement of materials and products; (2) *process control*, originated by W. A. Shewhart for the control of industrial manufacturing processes; (3) *design of experiments*, stemming from the basic work of R. A. Fisher and others on biological experimentation; (4) *sampling*, developed by J. Neyman, F. Yates, and others, for large-scale sample surveys in agriculture and the social sciences. The first, acceptance inspection, is vital in the preparation of purchase specifications for materials and products. The second and third, process control and design of experiments, are intimately related to measurement; the last three, sampling now included, bear directly on testing. All four are important functions of the Bureau.

Acceptance Inspection

The usual purpose of acceptance inspection is to assure the purchaser that the goods he buys are of the specified quality. Before World War II the most common inspection procedure was a form of screening in which bad items were weeded out of an incoming lot and returned to the supplier for replacement. Now, however, it is becoming more common to use a form of lot-by-lot acceptance inspection: Whenever the number of defective units in the lot exceeds a specified tolerance, the whole lot is rejected. This requires the submission of lots of acceptable quality. If the product is not screened before shipment, or in some other way checked as to its quality, the whole shipment may be rejected.

Process Control

The best check a supplier can employ on the quality of his product is process control. In industrial production this involves two things: A continual check on the quality of the product, usually by sampling at regular intervals, and a statistical interpretation of these measurements for the purpose of diagnosing the cause of any irregularity. If the measurements for a series of production samples are plotted on a control chart in the order in which they are taken, then trends, shifts in level, changes in variability, and other irregularities are detected quickly so that the trouble may be corrected before very much bad material is produced.

The techniques of process control can be applied as well to a measurement process in research or testing. In fact a method of laboratory measurement may be thought of as a production process in which the output is a series of numerical values of some physical quantity. Process control can be used to reveal whether or not the measurements are all of the same physical quantity. If this is not known, the validity of the final results of an experiment or test must remain in doubt. Process control makes it possible to trace variations to different factors in the measurement situation, such as individual differences among operators and changes in the experimental environment. Once these are known for a particular measurement scheme, they can be taken into account in the planning of experiments so the final results will not be affected by these variables. On many occasions laboratory process control leads to an improvement in the measuring techniques themselves by pointing out variations that might otherwise be overlooked.

Design of Experiments

Applied statisticians have become interested in the organization and planning of experimental programs, because they have found that more useful results can be obtained in a given experiment if certain statistical procedures are observed. The formulation of these procedures and their application under different circumstances is a branch of statistical engineering. Here the statistician can help the experimenter to design his experiments so that they will correspond to manageable mathematical models. If this is done, the validity of the statistical analysis is assured.

Another aspect of the planning of experiments involves the application of statistical methodology to the questions of how many measurements should be made, how many repetitions, how large a scale. The right decisions on these questions make for greater efficiency in experimental research.

An example of one of the more rewarding developments in the realm of experiment design is a scheme for comparing members of a group with one another when the group is too large to allow comparison of all members at once. Some of the members of the group must then be examined under conditions that may differ in some way from those that prevailed when the others were examined. Practically, this problem arises when all the tests cannot be made on one stock of homogeneous material, or in the same laboratory, or on the same day. Studies in the design of experiments have shown, however, that it is possible to choose overlapping subsets from the whole group in such a way that these differences will be effectively cancelled out in the final results. This gives nearly the same precision as would be obtained if all members were tested under identical conditions.

Sampling

Sampling has come to be widely used wherever information about large aggregates must be obtained without testing every member. The real problems in sampling come about when the material under study is not homogeneous—public opinion polls are the best known example. Industrially, this is important for bulk materials such as coal, wool, iron ore, and cement. Although the theory of unit sampling has been well explored, the subject of bulk sampling is not yet well understood.

One of the valuable wartime developments in the subject of sampling was a sampling plan known as sequential testing. In sequential testing the results of the first measurements taken determine whether additional samples must be drawn. This scheme cuts the amount of inspection in half without significantly increasing the risk of accepting bad material.

Because the modern contributions to statistical method are inadequately treated in the literature of physical science and engineering, the Statistical Engineering Laboratory has been active from its very beginning in bringing them to the attention of scientists and engineers at the Bureau, other laboratories, and in industry.

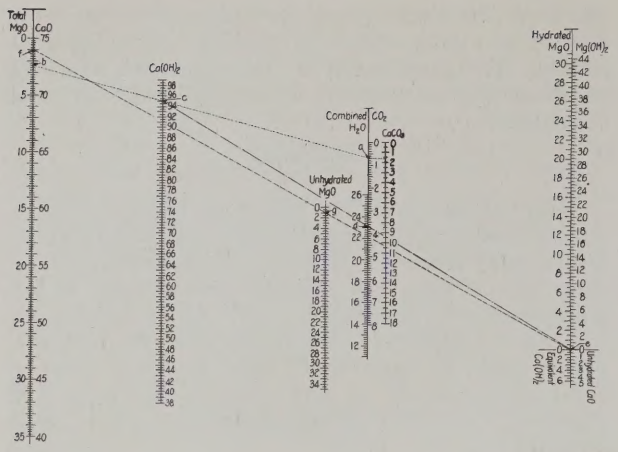
Nomograms Provide Compound Composition of Hydrated Limes

Nomograms developed by Ernest M. Levin of the National Bureau of Standards simplify computation of the compounds that are present in hydrated limes.[11] Knowledge of these compounds has become important in the selection of limes to be used in white coat plasters. The satisfactory use of lime for construction purposes dates back over 2,000 years. Consequently, considerable interest followed the disclosure by investigators at the Bureau that one variety of present-day lime was unsound and that its use caused expansion failures in plastered walls.

About 13 years ago, the Bureau became actively interested in a type of white-coat plaster failure that was becoming more and more prevalent and that was of tremendous concern, particularly to the Government, but also to the public in general. The specific type of failure was found to be associated only with regularly hydrated dolomitic limes and was characterized by the appearance of bulges or large blisters in the white-coat, several years after application. Furthermore, it has since been proved that the failure results from a delayed expansion of the set white-coat plaster. The hydrated dolomitic lime that is mixed originally with the gauging plaster and water to compound the wet plaster is not completely hydrated, and as a result, the plaster contains some unhydrated material (MgO) at the time of application. This material continues to hydrate slowly after the plaster has set, eventually causing the disruptive expansion.

This type of failure results from an important change in the manufacturing process and subsequent handling of lime. Until the start of the century, lime for construction purposes was supplied chiefly as quicklime, and accepted practice was to age the quicklime as a putty for several weeks. Because of the heat generated in the mass of putty and the long aging period, the quicklime was almost completely hydrated before it was compounded into plaster. However, lime is now prepared and sold in a hydrated form that requires soaking only overnight. Unfortunately, with dolomitic quicklimes the manufacturing process yields a lime that still contains about 27 percent, by weight, of unhydrated

[11] For more complete details and full size nomograms see, Nomograms for obtaining the compound composition of hydrated limes from the oxide analysis, by Ernest M. Levin, NBS Misc. Pub. M196 (1949). Available only from Superintendent of Documents, Government Printing Office, Washington 25, D. C., at 25 cents a copy.



Example of the use of nomograms to obtain the composition of a hydrated lime.

Essential oxide analysis

	Percent
CO_2	0.70
CaO	72.60
Combined H_2O	23.06
Total MgO	1.04
Subtotal	97.40

Procedure	Percent
1. Locate line ab (CO_2, % to CaO, %):	
At right of (a) read $CaCO_3$	1.6
At (c) read $Ca(OH)_2$	95.0
2. Locate line cd ($Ca(OH)_2$, % to combined H_2O, %) and extend to e (hydrated MgO, %):	
At (e) read $Mg(OH)_2$	0.0
3. Locate line ef ($Mg(OH)_2$, % to total MgO, %):	
At (g) read unhydrated MgO	1.0
Subtotal	97.6

material (MgO). High-calcium quicklimes are completely hydrated by the process, but these limes are not used generally for finish-coat plasters.

In the course of the investigation at this Bureau, methods were developed for determining the percentage of unhydrated material remaining in a hydrated lime. The Bureau, assisted by other Government agencies, formulated a specification that would exclude partially hydrated dolomitic limes containing a high percentage of unhydrated oxides. An 8-percent limit on unhydrated oxides was adopted as a tentative amendment to Federal Specifications for Hydrated Lime, and the same limit was included recently in specifications of the American Society for Testing Materials and in those of the American Standards Association. Numerous manufacturers of regularly hydrated dolomitic lime are producing at the present time a more completely hydrated lime that meets the 8-percent maximum limit. In most instances, this is accomplished by means of large autoclaves in which the quicklime is hydrated at elevated temperatures and pressures.

Determination of the composition of hydrated limes, particularly the unhydrated oxide content, is of obvious importance both to the manufacturer and to the prospective purchaser. The actual computation of the compound composition is made from the chemical (oxide) analysis and requires about nine mathematical operations of addition, subtraction, and multiplication. In order to save the time and labor involved in these calculations, two nomograms have been constructed for making the computations graphically. With the use of these nomograms the compound composition of any commercial hydrated lime can be determined easily and rapidly and with sufficient accuracy to be a valuable aid to the technologist in the lime plant or commercial testing laboratory.

Resin Bonding of Hardwood Fibers in Offset Papers

Further studies made at the National Bureau of Standards in the manufacture of resin-bonded papers [12] indicate that larger quantities of hardwoods may be utilized in making offset papers. The synthetic resin, which imparts the necessary printing properties to these papers, is a substitute for the natural fiber-bonding gel usually developed through the use of large amounts of softwood pulps. Current investigations in the Bureau's experimental paper mill show that resin-bonded papers containing 75 percent of hardwood pulps compare favorably with papers made in the conventional way with the customary combination of equal parts of hardwood and softwood fibers. An increase in the proportion of hardwood fibers in printing papers would greatly extend critical pulpwood resources, not only in this country but also in Europe where the stands of hardwood suitable for papermaking are much more extensive than those of softwood.

The strength of paper depends on the strength of its fibers and on the adhesive bond between them. In papermaking processes using softwood pulps the bonding agent is produced by beating the pulp in water causing some of the cellulose to gelatinize (hydrate) and form gel-like bonds between the fibers of the finished sheet. Because of the large increase in external surface (fibrillation) produced by beating, the number of contacts and subsequent bonds is greatly increased, thereby increasing the strength of the paper.

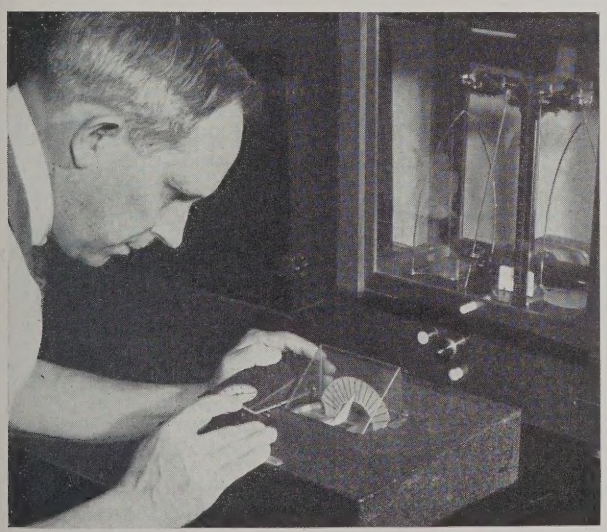
[12] For further technical details, see Resin bonding of hardwood fibers in offset papers, Bourdon W. Scribner, Merle B. Shaw, Martin J. O'Leary, and Joshua Missimer to be published in J. Research NBS; see also Resin-bonding—A new development in paper making, NBS Tech. News Bull. **32**, (Aug. 1948).

The hardwoods do not develop good bonding quality to the extent that conifers do.

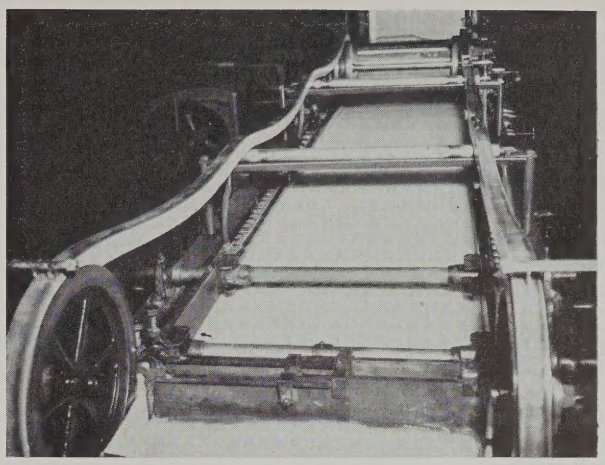
The development of strength by beating the fibers tends nevertheless to adversely affect some properties needed for good printing quality. Chief among these are high opacity, good oil absorption, high permeability to air, low expansivity, and low curl. Low expansion and contraction is particularly important in lithographic offset papers for good register of successive color prints, as in the case of printing maps that are often run through the press as many as 15 times. Hardwood pulps have all the properties needed for good offset printing paper except strength. The adverse effects arising from the beating process may be minimized by using synthetic resins as a binder, which also permits a large reduction in the beating time.

The present investigation was made with a variety of hardwood pulps produced at the U. S. Forest Products Laboratory in an experimental study of the pulping of aspen, black gum, paper birch, and beech. The pulps were prepared by the mechanical (groundwood), sulfate, soda, sulfite, and neutral sulfite processes.

As in the previous Bureau study, the use of small amounts of melamine-formaldehyde resin produced papers having good strength and resistance to pick, combined with a low expansivity and curl with a minimum of beating. The pulps that gave the best results comprised aspen sulfate, aspen soda, aspen sulfite, birch sulfite, and black gum sulfate. In the new processes the ratio of softwood to hardwood pulps was reversed, and up to 75 percent of the hardwood fibers could be used effectively. The proportion of hardwood fibers that can be used in the conventional printing papers is limited because they are short, weak fibers that impart little strength to paper. It is the softwood fibers used with the hardwood fibers that give the required strength.



The degree of curl of a resin-bonded paper is being measured with the standard curl tester developed at the Bureau. A low amount of curl is an important quality that a high grade offset paper must have; this property is determined when the paper is wet on one side.



After leaving the head box where the synthetic resin is added, the paper stock flows onto a finely woven, continuous wire screen on which the paper is formed. The feed end of the wire is vibrated sideways so that the fibers are intertwined, interwoven, and felted together. Excess water is removed by suction boxes, pressure rolls, and dryers near the other end of the machine.

Efficient use of large quantities of hardwood is an outstanding pulpwood problem. During the present century the pulp and paper industry has experienced an amazing growth, yet the supply of the more generally used pulp woods—the most important source of paper-making material—is steadily decreasing. Pulp produced from coniferous or needle-leaved softwood trees, such as spruce, fir, and pine, is used to a much greater extent than that produced from the hardwood or broad-leaved trees, such as the various "poplars", birch, beech, and gum, commonly used for pulping. The use of hardwoods for pulping is good forestry practice, and in regions having a large volume of hardwood species or inferior trees unsuited for lumber or similar products, is an economic necessity.

In comparison with spruce and other softwoods, however, the use of hardwoods has been limited by the characteristics of the hardwood fibers. The characteristics that affect the manufacture of paper vary in kind and quantity with different woods. One differentiation is the length of fiber, which for hardwoods is approximately 1 to 1.5 mm and for coniferous wood, 2.5 to 4.5 mm. The fiber of the hardwood trees also has a different structure than that of the conifers. Its soft and absorbent texture renders it useful for bulky papers, such as certain classes of printing paper, but it is not as strong as the softwood fiber.

The paper-making equipment at the Bureau is semi-commercial in size and is adapted to the experimental manufacture of papers under conditions that simulate in many respects those of typical industrial plants. The equipment used in this particular work consisted essentially of a 50-pound beater with copper-lined tub and manganese-bronze bars and plate; a jordan refiner with bars of bronze and steel alloy; a four-plate, flat screen; a 29-inch fourdrinier paper-making machine with a wire 33 feet in length, two presses, nine

15-inch dryers, a calender stack of seven rolls, and a reel; and a five-roll supercalender.

A series of papers was made from the pulps with and without the resin bonding while the manufacturing factors were kept as nearly constant as possible. The pulps were beaten for 1½ hours, which was considered the minimum time for satisfactory results. This compares with a beating time of about 9 hours used in the conventional manufacture of offset papers.

Fifty pounds of pulp and 1 percent (based on weight of fiber) of resin size were used for each machine run. The melamine-formaldehyde resin was added in the form of a colloidal solution made by dissolving the powdered resin in warm water acidified with hydrochloric acid. The solution was added continuously at uniform rate to the papermaking stock just before it entered the head box of the paper machine where the temperature was maintained at 90° F. The particles of the colloidal resin have a positive charge and, since cellulose is negatively charged, they are therefore quickly absorbed on the cellulose fiber. The heat of the paper-machine drying cylinders completes the polymerization of the resin particles, forming a water-insoluble bond between the fibers. The finish imparted by the small paper machine calender was relatively low, therefore the papers were given light supercalendering to obtain a smoothness comparable to commercial "machine finish".

The Geiger-Müller Counter

The nature, construction, and use of the Geiger-Müller counter, one of the most important of present-day detectors of radioactive radiation, is concisely presented on an elementary level in a new booklet just published by the National Bureau of Standards.

In addition to the treatment of the Geiger-Müller counter itself, the booklet discusses methods of detecting counter pulses, applications of counters to quantitative measurements, proportional counters, and the preparation and filling of Geiger-Müller counters. Also included are a number of examples of special forms of counters that have been developed and a discussion of some of the electronic circuits commonly used to obtain an indication of the response of the counter to radiation. For those readers who wish to pursue the subject in more detail, a bibliography of scientific papers is presented.

Circular 490, *The Geiger-Müller Counter*, 25 large double-column pages, illustrated, is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., 20 cents a copy. Remittances from foreign countries should be in United States exchange and should include an additional sum of one-third the publication price to cover the cost of mailing.

NBS Publications

Periodicals [13]

Journal of Research of the National Bureau of Standards, volume **44**, number 2, February 1950. (RP2062 to RP2071, inclusive).

Technical News Bulletin, volume **34**, number 2, February 1950. 10 cents.

CRPL–D66. Basic Radio Propagation Predictions for May 1950. Three months in advance. Issued February 1950. 10 cents.

Nonperiodical [13]

Research Papers [13 14]

RP2053. The 1949 scale of color temperature. Deane B. Judd.

RP2054. Note on the disintegration of wool in abrasion tests. Herbert F. Schiefer and John F. Krasny.

RP2055. A bolometer bridge for standardizing radio-frequency voltmeters. Myron C. Selby and Louis F. Behrent.

RP2056. Influence of temperature on the adsorption of water vapor by collagen and leather. Joseph R. Kanagy.

RP2057. Soil corrosion studies, 1946: Ferrous metals and alloys. Irving A. Denison and Melvin Romanoff.

RP2058. Transmission of reverberant sound through double walls. Albert London.

RP2059. Solution of the telegrapher's equation with boundary conditions on only one characteristic. George E. Forsythe.

RP2060. Table of modified Bernoulli polynomials. Gertrude Blanch and Roselyn Siegel.

RP2061. Electrodeposition of alloys of phosphorus with nickel or cobalt. Abner Brenner, Dwight E. Couch, and Eugenia Kellogg Williams.

Circulars [13]

C490. The Geiger-Müller counter. Leon F. Curtiss. 20 cents.

Commercial Standards [13]

CS42–49. Structural fiber insulating board. (Fourth edition) (Supersedes CS42–43). 10 cents.

CS160–49. Wood-fiber blanket insulation. 5 cents.

CS161–49. "Standard grade" hot-dipped galvanized ware (coated after fabrication). 5 cents.

Miscellaneous [13]

M195. Report of the Thirty-Fourth National Conference on Weights and Measures. 35 cents.

M196. Nomograms for obtaining the compound composition of hydrated limes from the oxide analysis. Ernest M. Levin. 25 cents.

Simplified Practice Recommendations [13]

R90–49. Hack-saw blades. (Supersedes R90–46). 5 cents.

Articles by Bureau Staff Members in Outside Publications [15]

The development of American physics. E. U. Condon. Am. J. of Physics (57 E. Fifty-fifth Street, New York 22, N. Y.) **17**, 404 (1949).

Viscosity of solutions of macromolecules. Robert Simha. Record of Chem. Progress (Kresge-Hooker Scientific Library, Wayne University, Detroit 1, Mich.) **10**, 157 (1949).

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[13] Send orders for publications under this heading only to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Annual subscription rates: Journal of Research, $4.50 (foreign $5.50); Technical News Bulletin, $1.00 (foreign $1.35); Basic Radio Propagation Predictions, $1.00 (foreign $1.25). Single copy prices of publications are indicated in the lists.

[14] Reprints from January Journal of Research.

[15] These publications are not available from the Government. Requests should be sent direct to the publishers.

U. S. GOVERNMENT PRINTING OFFICE: 1950